CONSTRUCTED WETLANDS FOR WASTEWATER TREATMENT IN ITALY: STATE-OF-THE ART AND OBTAINED RESULTS

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ABSTRACT

The Italian Section of the IWA Specialist Group on The Use of Macrophytes for Water Pollution Control was established at the end of 1999. The Group is collecting data (process, design criteria, plant utilization, removal efficiency, economic and legislative aspects, etc.) on the existing plants operating in Italy in order to contribute to the development of a reference manual to be used by engineers and administrators for the design and the evaluation of constructed wetlands (CWs). Since the 1980's over a hundred constructed wetlands, both free water and subsurface (horizontal and vertical) flow systems, have been carried out in Italy. Most of the facilities are located in the northern and central part of Italy. A good efficiency in the removal of organic content, Nitrogen and Suspended Solids was observed, both in secondary and tertiary treatment plants, despite a general lack of monitoring data.

KEYWORDS

Constructed wetland; Reference manual; Wastewater treatment; COD removal; Nitrogen removal; Suspended Solids removal

INTRODUCTION

Development of constructed wetlands in Italy

Until 1999, constructed wetland technology was not considered a treatment technology by the Italian legal framework (the technology was not considered in the technical acts following law n.319 of 1976 concerning water pollution): this is one of the main reasons why this technology has spread much less in Italy compared to other European countries, despite Italian good climatic conditions. With the enforcement of a new law (D.Lgs. n.152 of 1999), which implements EC Directive 91/271 about municipal wastewater treatment, constructed wetlands have been "officially" recognized as treatment technology. The use of constructed wetland is specifically advised by D.Lgs 152/99 for urban centers with populations in the range of 10-2000 PE discharging into freshwater, in the range of 10-10.000 PE discharging in sea water, and for tourist facilities and other point sources with high rates of fluctuation of organic and/or hydraulic loads.

On the basis of European and North American experiences, research groups, public administrations and private societies in Italy have experimented for about ten years on the applicability of constructed wetlands for wastewater treatment. In spite of a first step that brought to poorly designed and malfunctioning systems because of a lack of applicative experiences, the development of constructed wetlands has not stopped. The coordinated action of the National Environmental Protection Agency (ANPA), of the National Institute of Energy and Environment (ENEA), of some university research groups and of the IWA specialist group is actually leading to the definition of common design criteria and to the establishment of a nationwide monitoring network. This has allowed obtaining data to be compared, analysed and used to calculate new process kinetic constants and to understand the functioning dynamics. The identified features enable to outline specific guidelines for the Mediterranean area, thus avoiding the use of American or North-European models (Brix, Reed, Kadlec, Cooper). During 1999, Dr. Andrea Innocenti, University of Torino, has collected data about 150 systems for his degree thesis in Natural Sciences. Some plants are non-active or don't exist anymore due to their experimental nature or because of the 1994 floods in the region Piemonte (Fig. 1). Whilst this census is certainly not exhaustive, it represents the most detailed investigation available at the moment. It is believed, however, that the number of existing constructed wetlands in Italy is likely to be higher. The collected data are related to: location, design parameters and treatment results.

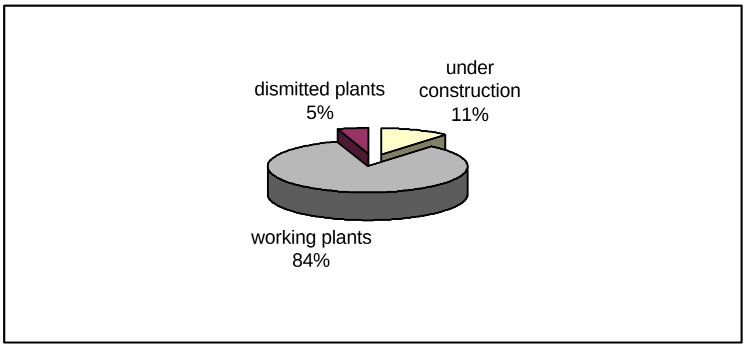

Fig.1 - Current state of constructed wetlands in Italy

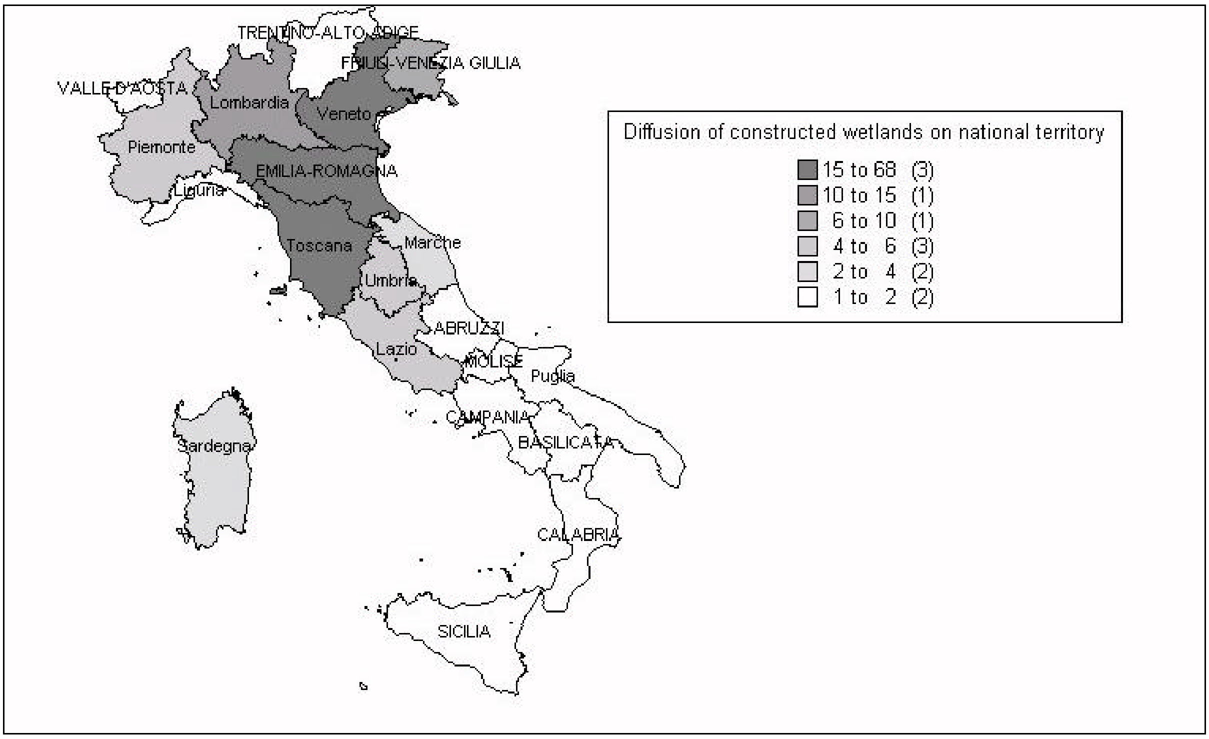

Fig. 2 - Geographical distribution of constructed wetlands in Italy

It may be noticed from the map shown in Fig. 2 that constructed wetlands have an irregular geographical distribution, with most systems concentrated in central and northern Italy. Out of 145 systems, 106 (74%) are located in Veneto, Emilia-Romagna and Toscana. In these regions, the higher distribution is strictly influenced by favourable local conditions.

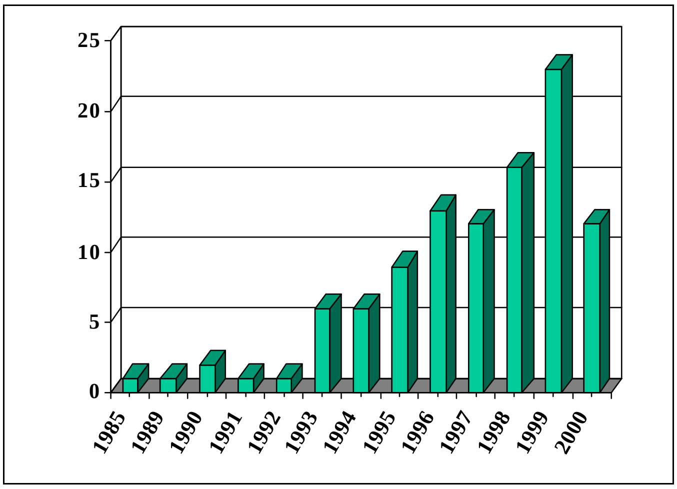

Fig. 4 - Total number of constructed wetlands built in Italy from 1985 until today

Fig. 4 shows the increasing number of CWs realizations from 1985 to 2000. The new legislative acceptance will further the development of this kind of wastewater treatment.

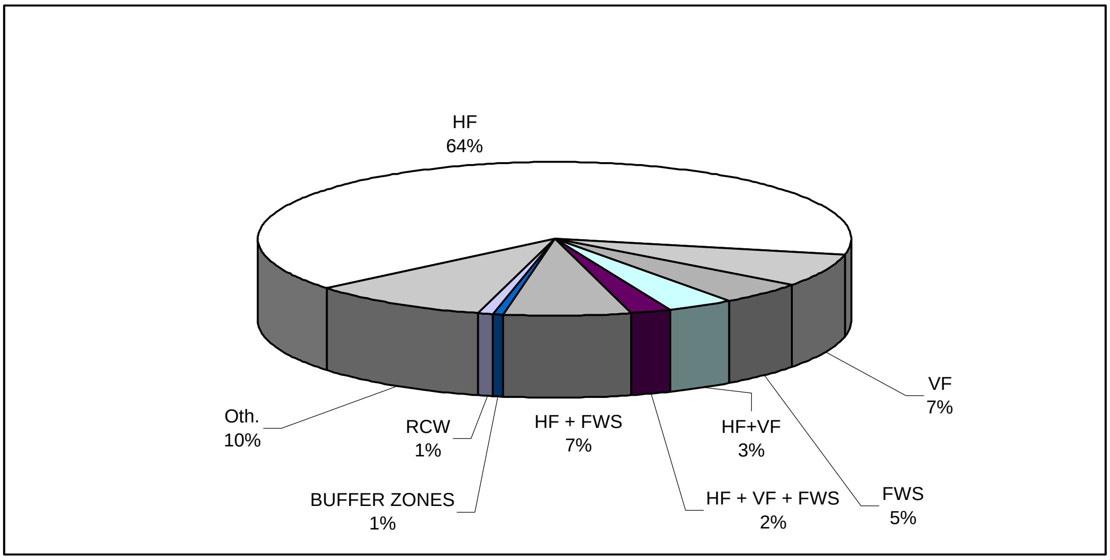

Fig. 5 - Kinds of constructed wetlands in Italy

Different kinds of plants have been constructed, even if horizontal subsurface flow systems (HF) prevail. At present, nearly 90 HF CWs are in operation. Unfortunately only 14 of them have been regularly monitored and, therefore, the results showed in this paper are referred to data related to a small fraction of the whole number of plants (about 10%).
Only 11 vertical subsurface flow systems CWs (VF) are in operation and 3 of them have been monitored. The majority of both HF and VF CWs systems (about 70 plants) have been installed to treat domestic or municipal wastewater as secondary treatment stage. Most of HF systems are designed with the specific area of 3-5 m^2 PE^{-1} (PE = Population Equivalent; 60 g BOD_5 per person per day), while VF systems (about 10 plants) show a design specific area of 2-3 m^2 PE^{-1}.
Otherwise, Free Water Systems CWs (FWS) are prevalently used for tertiary treatment of existing activated sludge plant, with a specific area of about 1.5 m^2 PE^{-1} (9 plants), or combined, as a final stage, with HF and VF systems to obtain a better pathogens removal or to refine the wastewater treatment with the aim of reuse it (5 plants).
Semi-natural (NW) and re-constructed systems (RCW) are also present in Italy in a small amount (2 plants). RCWs are designed for the treatment of diffuse pollution sources from agricultural and civil catchments, and were realised in areas were the soil characteristics and the hydrology of the area were suitable to develop quickly to wetland condition and to limit groundwater release. They are based on the reproduction of terrestrial and aquatic successions of ecosystems more than on the growth of one population. Limitations to the application of these systems seem to be represented by a more precise understanding of input loading thresholds and process modelling. The power of these systems is the multi-functionality at the landscape scale, most of all in environmentally sensitive areas.
The main fields of application of wastewater treatment or water pollution control by constructed or re-constructed (semi-natural) wetlands are summarized in Table 1.

Table 1. Number of natural wastewater (WW) treatment plants per field of application and total number of Population Equivalent treated (PE_{tot}) for each field

	HF	VF	FWS	Hybrid	Lemna	RCW	NW	PE_{tot}
Municipal – Domestic WW Secondary treatment	61	10	2	13	3	-	-	25.500
Municipal – Domestic WW Tertiary treatment	3	2	6	4	1	-	-	79.500
Industrial WW	27	-	-	5	1	-	-	-
Agricultural runoff	1	-	-	-	-	-	2	-
Polluted Rivers or Channels	-	-	-	-	-	1	-	-
Landfill Leachate	1	-	-	-	-	-	-	-
Sludge dewatering	-	1	-	-	-	-	-	-

The industrial wastewaters treated are: food processing waste (vegetables, oil, wine, cheese, beer), car-washers and small breeding farms.

STATE OF CWs IN ITALY

Applications

From the analysis of the Italian experiences early reported, the following general considerations emerged referring to the wastewater secondary and tertiary treatment.

Constructed wetland for secondary treatment

When correctly dimensioned subsurface flow systems guarantee the best results during the whole year and shows the best relation between used areas and goals to be achieved.
A subsurface stage in every constructed wetland for secondary treatment is therefore suggested, considering a free water in multi-stage systems only to cut down either hygienic parameters or nutrients or for reclamation concepts.

Horizontal flow systems

Widespread in European and international applications, horizontal flow systems are at the moment the most monitored, so that dimensioning equations and provisional models on removal rate of the most polluting chemicals are available and comparable (Vymazal et al., 1998; DLWC-NSW, 1998; IWA, 2000).
Systems implemented with dimensioning criteria like 3-5 m^2 PE^{-1}, gravel-based with a mean grain size < 10 mm, with slope of beds of 1-2 % and mean depth of beds of 0.7 m (Del Bubba, 2000; Garuti, 2000; Masi, 1999) show the best results in the removal of

organic load, suspended solids, hygienic load, irrespective of the variations in hydraulic load, of the characteristics of water treated and of seasonal temperature changes. According to the experiences in the Mediterranean it seems that that increasing the area coefficient to 4 m^2 PE^{-1}, may cause the law-limits to be exceeded in the cold period of the year for nitrogen removal. The present national law on wastewater discharge, however, does not consider this parameter for plants treating less than 2000 PE and discharging into open water bodies, and the suggested criterion for the efficiency evaluation of the treatment process is to define the removal percentage for organic matter and total suspended solids. In agreement with international literature, it was also found that nitrification and N-Ntot removal are more sensible to temperature variations (Del Bubba, 2000; Garuti, 2000; Masi, 1999), so that bigger area coefficients are suggested to reach the concentration limit for discharge on soil (Tab.4 All. 5 DL 152/99): 7-9 m^2 PE^{-1}.

In 10 monitored Italian HF CWs systems applied as secondary treatment plants for municipal and domestic wastewater, hydraulic retention times (HRT) plants are between 3-4 days. Fig. 6 shows the loose relationship between inlet and outlet COD (average annual concentrations) in those plants. This relationship shows a great independence of outlet concentrations from the inlet ones, in agreement with similar results obtained for BOD_5 by Vymazal (1999) from 44 HF CWs in Czech Republic and by Brix (1998) from 100 HF CWs in Denmark.

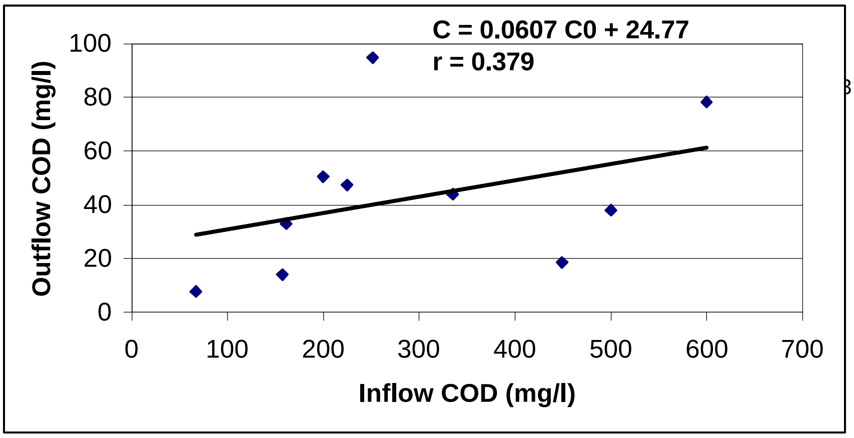

Fig. 6 – Relationship between COD concentrations in inflowing pretreated (Imhoff tank) wastewater and water outflowing from HF CWs systems (n=10). Each point represents an average annual COD concentration of a different plant.

The average overall treatment efficiency for COD removal in 10 systems was 83.7% (± 10.0%), strictly in agreement with other literature results (Reed, 1993; Maehlum et al, 1998; Vymazal, 1999).

In the same systems the average overall treatment efficiency for total suspended solids removal was 86.1% (± 15.3%), for ammonium it was 64.0% (± 29.4%) and for nitrates it was 94.5% (± 7%).

Vertical flow systems

From the analysis of the 1000 experiences existing in Europe (Vjmazal, 1998), the interest in this kind of system is growing faster, specially considering the applications in Greece, Germany, Austria, Netherlands, United Kingdom. Vertical flow systems are not so widespread in our country. The few experiences show very good results most of all for nitrification capacity and lower request of area with respect to HF. All the monitored vertical filters show a good capacity in oxidation created with the intermittent loading and the consequent emptying of the reed bed, so that ammonium removal and production of $N-NO_3^-$ occur. A problem related to this kind of system is the filter clogging so that it seems better to use them after a little HF system (combined or hybrid systems) or a stabilization pond, paying attention to the inlet having a low rate of suspended solid. VF systems can be used as oxidation stage (nitrification and oxidation of organic load) followed by an adequate HF system for denitrification.

The first results obtained from two small size plants for domestic wastewater treatment and on three different research experiences with pilot plants, show a good removal of ammonium (60-90%) together with a higher removal of COD (92-99.9%) and BOD_5 (97-99%). Both experimental plants are sized with a specific area of about 3 m^2/ae and are filled with sand.

Constructed wetland for tertiary treatment

Because of their intrinsic characteristics such as strong flexibility to variation of either organic and mass load, easy maintenance, good adaptability in the landscape, constructed wetlands are used to refine the outlet of conventional waste water treatment plants (especially those that employ activated sludge), in order to buffer malfunctioning events or to obtain high levels of disinfection for the reuse of treated water in agriculture.
The most common engineering solutions for post-treatment in our country are usually HF+FWS with preference for FWS for systems over 20.000 inhabitants/ equivalent.

Of the 16 tertiary treatment CWs plants currently operating in Italy, only 6 have been regularly monitored. Two single stage HF systems, treating effluents from activated sludge plants, are obtaining optimum COD and Nitrates removal efficiencies, in the order of 59-88% and 78-84% respectively.

Research

At present in Italy there are a lot of researches concerning CWs carried out both at university and in private companies.

Main Research Applications :

- Industrial applications: surfactant removal; high organic load (vegetation waters from olive oil production; dairy farms wastewater); heavy metal removal.
- Role of plants: some experimentations on different roles of macrophytes in wastewater treatment process; nutrient removal capacity of different macrophytes.
- Hygienic aspects: use of CWs as final stage to develope and increase water reuse.
- Sludge dewatering.

COMMENTS

Considering the good performances carried out, the positive impact on public opinion, the low operative costs and the very recent legislative directions, CW systems are going to become a significant instrument for wastewater treatment in our country.

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